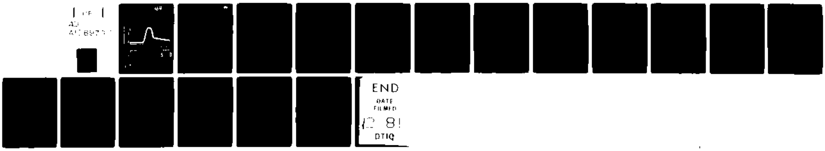
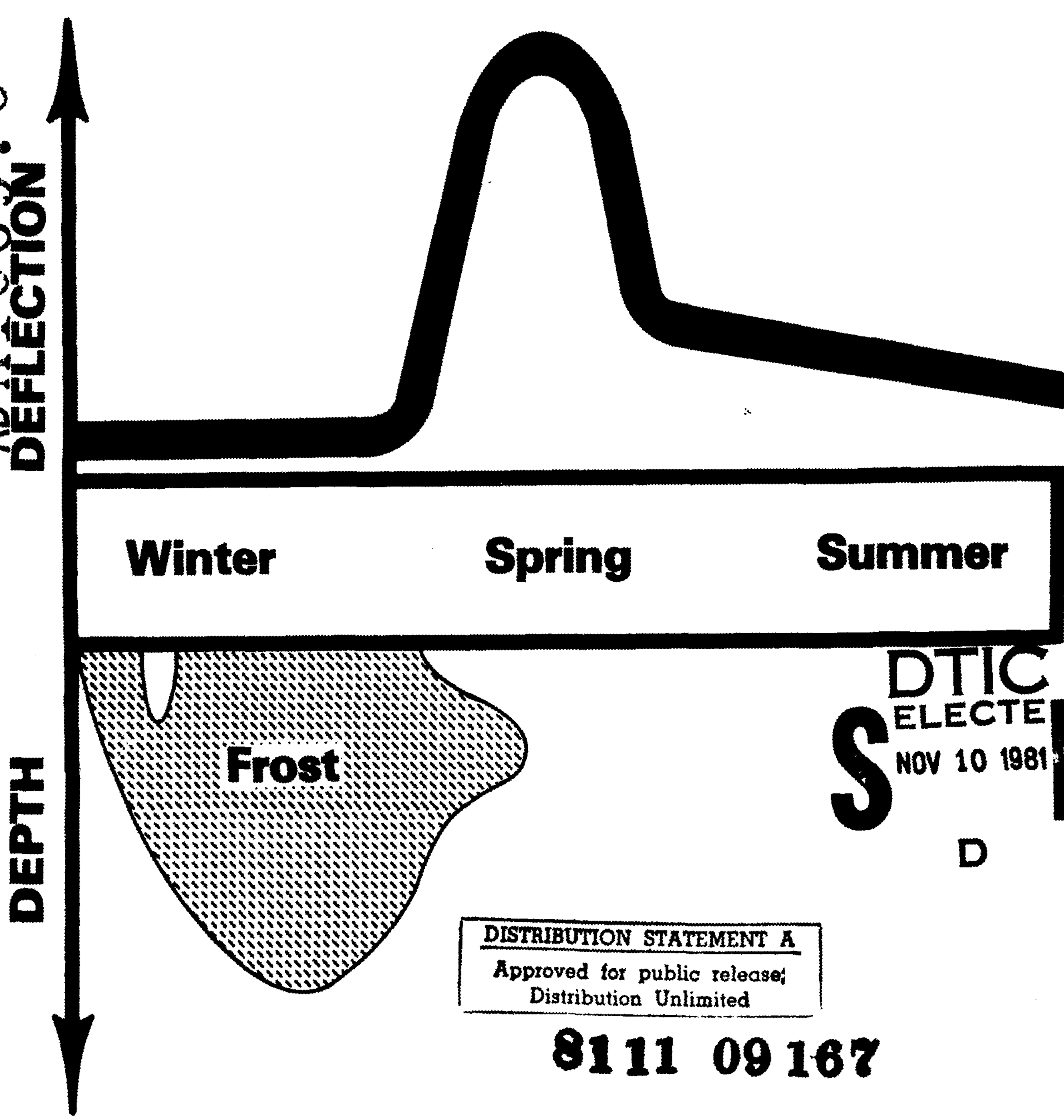
AD-A106 976 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH F/G 13/2
A STATISTICAL EVALUATION OF SOIL AND CLIMATIC PARAMETERS AFFECT--ETC(U)
JUL 81 E J CHAMBERLAIN
UNCLASSIFIED CRREL-81-15 NL



CRREL

REPORT 81-15

A statistical evaluation of soil and climatic parameters affecting the change in pavement deflection during thawing of subgrades



CRRL

CRREL Report 81-15

A statistical evaluation of soil and climatic parameters affecting the change in pavement deflection during thawing of subgrades

Edwin J. Chamberlain

July 1981

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS
By
UNITED STATES ARMY CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

12 38

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER CRREL Report 81-15	2. GOVT ACCESSION NO. AD-A106976	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A STATISTICAL EVALUATION OF SOIL AND CLIMATIC PARAMETERS AFFECTING THE CHANGE IN PAVEMENT DEFLECTION DURING THAWING OF SUBGRADES		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edwin J. Chamberlain		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project 4A762730AT42 Task A2, Work Unit 002
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Military Programs Office of the Chief of Engineers Washington, D.C. 20314		12. REPORT DATE July 1981 13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Deflection
Freeze-thaw
Pavement bases
Pavements
Soils
Statistical analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report analyzes the results of a field study previously reported by Scrivner et al. (1969) for the National Cooperative Highway Research Program. These authors studied the seasonal pavement deflection characteristics of 24 test sites on roads in service in regions with freezing indexes ranging from 100°F-days to 2100°F-days. They used the Dynaflect cyclic pavement loading device to determine the pavement system response. Of specific interest to my analysis was the increased pavement deflection after freezing and thawing and the time to recovery of normal deflection characteristics. These characteristics were related to soil and climatic factors using statistical techniques. The most significant observations of this statistical analysis are: 1) that the freezing index is not a significant parameter in determining the percent increase in pavement deflection during thawing, and 2) that the recovery time is inversely proportional to the depth of

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (cont'd).

freezing. As was expected, the most significant variable affecting the increase in pavement deflection was the frost susceptibility classification. This observation reinforces the necessity for careful selection of soil materials used in pavement systems.

PREFACE

This report was prepared by E.J. Chamberlain, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was funded under DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions;* Task A2, *Soils and Foundations Technology/Cold Regions;* Work Unit 002, *Seasonal Change in Strength and Stiffness of Soils and Base Courses.*

The research evaluated in this report was an original contribution of F.H. Scrivner, R. Peohl, W.M. Moore, and M.B. Phillips and was published by the National Cooperative Highway Research Program, Report No. 76, 1969.

This report was technically reviewed by T.C. Johnson and N. Smith of CRREL.

CONTENTS

	Page
Abstract	i
Preface	iii
Nomenclature	v
Introduction	1
Description of test site	1
Test results	3
Method of analysis	5
Results of analysis	5
Change in resilient deflection due to thawing, Δ	5
Recovery time after onset of thawing, t_{20}	7
Discussion of results	7
Change in resilient deflection due to thawing, Δ	7
Recovery time after thawing, t_{20}	9
Conclusions	9
Literature cited	10

ILLUSTRATIONS

Figure	
1. Pavement deflection and frost penetration vs time	2
2. Data points and regression line for Δ and t_{20} versus F	6
3. Data points and regression line for Δ and t_{20} versus W_{1n}	8
4. Data points and regression line for Δ and t_{20} versus I	7
5. Data points and regression line for Δ and t_{20} versus N	8
6. Data points and regression line for Δ and t_{20} versus D	8
7. Data points and regression line for t_{20} versus Δ	8
8. Permeability vs void ratio for the Toledo Penn 7 material	10

TABLES

Table	
1. Properties of test sections	3
2. Test results from Scrivner et al.	4
3. Results of regression analysis	6

NOMENCLATURE

$a_0, a_1, a_2, a_3, a_4, a_5$	regression coefficients for Δ equation
$b_0, b_1, b_2, b_3, b_4, b_5, b_6$	regression coefficients for t_{20} equation
t_{20}	time to recovery of all but 20% of W_{1n} (days)
D	maximum depth of frost penetration (inches)
F	Corps of Engineers frost susceptibility classification
I	freezing index (°F-days)
N	number of freeze-thaw cycles
W_{1max}	maximum spring pavement deflection (10^{-3}in.)
W_{1n}	normal fall pavement deflection (10^{-3}in.)
α	probability level for rejecting a variable
Δ	$[(W_{1max}-W_{1n})/W_{1n}]\times 100$ (%)

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
Inch	25.4*	Millimeter
Milli-inch	0.0254*	Millimeter
Pound	0.4535924	Kilogram
Ton	907.1847	Kilogram
degrees Fahrenheit	$t_{°C} = (t_{°F}-32)/1.8$	degrees Celsius

*Exact

A STATISTICAL EVALUATION OF SOIL AND CLIMATIC PARAMETERS AFFECTING THE CHANGE IN PAVEMENT DEFLECTION DURING THAWING OF SUBGRADES

Edwin J. Chamberlain

INTRODUCTION

Recent developments in the design of flexible pavement systems utilize mechanistic methods rather than the empirical design methods employed in the past. Rather than using the results of static load tests such as the plate bearing or California bearing ratio (CBR) tests, the new design methods require the input of resilient moduli for each of the layers in a pavement system. While preparing a recommended procedure for determining the resilient moduli of base, subbase, and subgrade materials during thawing, the author reviewed literature for both laboratory and field studies.

One field study that was of special prominence was reported by Scrivner et al (1969). Because this study provided a considerable amount of data for a variety of soil and climatic conditions, several of the potentially significant parameters affecting the change in pavement performance could be evaluated. Two factors were of interest: 1) the increased resilient pavement deflection during thaw, and 2) the time required for recovery of the resilient pavement deflection to prefrozen levels. In order to evaluate the influence of soil and climatic parameters on these factors, the author employed statistical techniques. The results were somewhat surprising and are presented here to stimulate discussion.

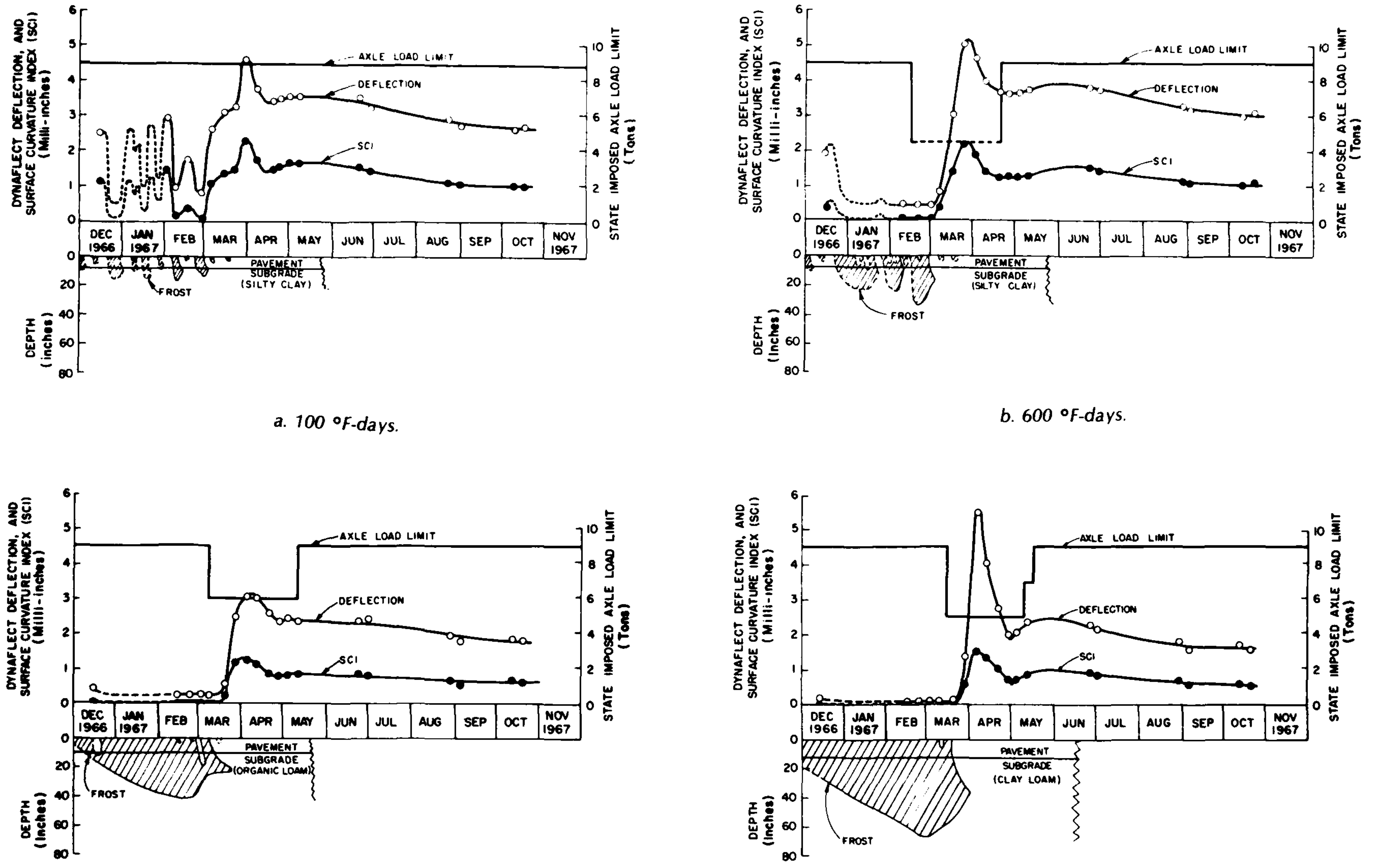
Scrivner et al. (1969) applied a cyclic load to existing flexible pavement surfaces using the Dynaflect, a pavement-mounted, cyclic pavement-loading device that applies a load of 1,000 lb at a frequency of 8 Hertz, and recorded the recoverable or resilient surface deflection. Six test sites at each of four areas between Springfield, Illinois, and Duluth, Minnesota, were observed over a 1-year period. The mean freezing index was 100°F-days in the most southerly of the regions and 2100°F-days in the most northerly. Where the freezing index was small (100°F-days) the frost penetration into the subgrade was shallow and intermittent, while where the freezing index was large (2100°F-days), the subgrade freezing was deep and uninterrupted. Figure 1 gives typical frost penetration for each climatic region.

This study analyzes the influence of the freezing index, the number of freeze–thaw cycles, the depth of frost penetration into the subgrade, and the subgrade soil type on the seasonal change of resilient deflection due to thawing and on the time after thaw to recovery of the normal pavement deflection.

DESCRIPTION OF TEST SITE

As shown in Table 1, a wide range of subgrade materials was encountered, from clay tills to sand fills, with silty clays being the most common. Base and subbase materials included native granular material, crushed stone, gravel, crushed rocks, sand–gravel, and NaCl-stabilized and bituminous-treated gravels. Pavements were predominantly asphalt concrete. A few surface treatment pavements were also encountered.

In each of the four study areas two of the six test sections were located on highways designed to carry relatively heavy traffic, and four were located on roads designed for light traffic. The test sections were 1000 feet in length. Pavement deflections at ten test points in the outer wheel path were observed over a period from December 1966 to October 1967. Approximately 20 visits were made to each test section during this period.



a. 100 °F-days.

b. 600 °F-days.

c. 1300°F-days.

d. 2100 °F-days.

Figure 1. Pavement deflection and frost penetration vs time. Typical plots for freezing indexes of a) 100, b) 600, c) 1300, and d) 2100 °F-days (from Scrivner et al. 1969).

Table 1. Properties of test sections (from Scrivner et al. 1969).

AREA	SEC. NO.	DESIGN CLASS.[a]	THICKNESS (INCHES) SURFACE	BASE	SUBBASE	MATERIAL TYPE SURFACE	BASE	SUBBASE	SUBGRADE
1	19	1	1 [b]	7	—	S.T.	Gran. matl.	—	Silty clay
1	20	2	4.5	8	6	A.C.	Cr. stone	Cr. stone	Silty clay
1	21	1	2.5 [b]	6.5	—	S.T.	Cr. stone	—	Silty clay
1	22	1	4.3 [b]	6	—	S.T.	Gravel	—	Silty clay
1	23	1	2 [b]	7	—	S.T.	Cr. stone	—	Silty clay
1	24	2	4.5	9	6	A.C.	Cr. stone	Gravel	Silty clay
2	13	1	0.5 [b]	8	—	S.T.	Gravel	—	Silty clay
2	14	1	0.5 [b]	4	4	S.T.	NaCl stab. gr.	Gravel	Silty clay
2	15	1	2	8	—	A.C.	Gravel	—	Clay till (some gravel)
2	16	1	0.5 [b]	4	4	S.T.	Gravel	Gravel	Silty clay
2	17	2	3	10	—	A.C.	Cr. stone	—	Sand fill
2	18	1	2 [b]	7 [b]	—	A.C.	Gravel	—	Silty clay
3	1	1	3	3	9	A.C.	Cr. rock	Sand-gravel	Silty clay loam
3	2	1	4	16.5	—	A.C.	Gravel	—	Silty clay loam
3	3	1	2	3	9	A.C.	Cr. rock	Sand-gravel	Organic loam
3	4	1	1.5	9	—	A.C.	Gravel	—	Organic loam
3	5	2	3	6	12	A.C.	Cr. rock	Sand-gravel	Silty loam
3	6	2	6	4.5	12	A.C.	Gravel	Sand-gravel	Clay till (some gravel)
4	7	1	6	13	—	A.C.	Gravel	—	A-7-5 clay
4	8	2	6	16.5	—	A.C.	Gravel	—	Gravel fill on sandy loam
4	9	1	4	3	9	A.C.	Gravel	Gravel	Gray and red clay
4	10	1	4	9	—	A.C.	Sand-gravel	—	Clay loam
4	11	1	3	3	9	A.C.	Gravel	Sand-gravel	A-6 clay to A-4 sandy loam
4	12	2	8	4	12	A.C.	Bit. treat. gr.	Gravel	Sand fill

[a] 1—Design for light traffic. 2—Design to carry relatively heavy traffic.
[b] Thickness determined by drilling.

Thermocouples were installed at two locations within each test section. The depth of frost penetration was determined from the position of the 32° isotherms and averaged for each of the two locations in each test section.

TEST RESULTS

Figure 1 shows typical results for each of the four study areas. Figure 1a shows that in the most southerly locations (freezing index = 100°F-days), the frost penetration into the subgrade was shallow and intermittent. Several freeze–thaw cycles occurred over the winter period. Farther north, where the freezing index was 600°F-days, the frost penetration was still intermittent but the frost depth was significantly greater. Still farther north (1300°F-days freezing index), the frost penetration was more or less continuous over the winter and approached 40 inches. At the most northerly location (2100°F-days freezing index), the frost penetration into the subgrade was uninterrupted and exceeded 60 inches.

In each of these representative plots the spring thaw is accompanied by an upward spike in the Dynaflect deflection curve. Generally, the ratio of the magnitude of this spike to the normal fall deflection value appeared to be unrelated to freezing index in the examples shown in Figure 1. Only the most northerly site is an exception to this observation.

Figure 1 shows that the time to recovery was relatively short. The area under the spike generally covered a period of approximately one month. The spike is generally followed by a slight increase in deflection in the next month and finally a gradual decrease over the remainder of the summer.

Table 2 presents the test results for all test sites. The first column gives the section identification number according to Scrivner et al. (1969). The next column gives the freezing index (I), also as reported by Scrivner et al. The third and fourth columns give the number of freeze–thaw cycles (N) and the depth of frost penetration (D) into the subgrade as determined by the author from the reported data plots. The next column gives my estimate of the frost classification (F) of the subgrade material according to the Corps of Engineers system (U.S. Army 1965) where 1 is the lowest frost susceptibility class and 4 is the highest frost susceptibility class.

The next two columns show the pavement deflection data reported by Scrivner et al. (1969).

Table 2. Test results from Scrivner et al. (1969).

Section	I^1 Freezing index (°F-days)	N^2 Number of F-T cycles	D^3 Depth of frost penetration (in.)	F^4 Estimated frost classification of subgrade	W_{1n}^5 Normal fall deflection (10^{-3} in.)	W_{1max}^6 Maximum spring deflection (10^{-3} in.)	Δ% $[(W_{1max}-W_{1n})/W_{1n}]\times 100$	t_{20}^7 Time to recover from beginning of thaw (days)
19	100	7	10	3	2.76	4.60	67	49
20	100	0	0	3	1.86	2.30	24	35
21	100	8	6	3	2.24	4.10	83	54
22	100	4	4	3	1.71	2.70	58	52
23	100	4	6	3	2.34	4.16	78	60
24	100	4	0	3	1.21	1.84	52	55
13	600	4	26	3	3.14	5.20	66	50
14	600	4	22	3	2.52	4.42	75	47
15	600	4	22	4	2.21	4.05	83	53
16	600	3	18	3	2.42	4.20	74	58
17	600	4	34	2	0.90	0.97	8	42
18	600	4	18	4	1.96	3.30	68	48
1	1300	1	28	4	1.41	3.05	116	52
2	1300	1	40	4	1.14	1.90	67	44
3	1300	1	38	4	1.26	1.80	43	46
4	1300	1	30	4	1.85	3.12	69	51
5	1300	1	36	4	1.07	1.62	51	51
6	1300	1	31	2	0.81	1.15	42	47
7	2100	1	24	3	2.49	3.10	24	51
8	2100	1	64	3	0.90	1.32	47	42
9	2100	1	52	3	2.19	3.25	48	43
10	2100	1	56	4	1.64	5.60	241	45
11	2100	1	52	4	1.96	2.87	46	47
12	2100	1	78	2	0.60	0.62	3	40

Notes [1]From Table 3, Scrivner et al (1969)
[2]Number of freeze-thaw cycles into subgrade determined by author from Appendix B, Scrivner et al (1969)
[3]Depth of frost penetration into subgrade determined by author from Appendix B, Scrivner et al (1969)
[4]Estimate by author of frost classification according to U.S. Army (1965), F prefix is dropped for statistical analysis, soil data from Table 2, Scrivner et al (1969)
[5]Average deflection observed during August, September, and October, from Table 6, Scrivner et al (1969)
[6]Estimate by author from Appendix B, Scrivner et al (1969)
[7]Time to recovery of all but 20% of W_{1n}, from Appendix B, Scrivner et al (1969)

The normal fall deflection data (W_{1n}) were taken directly from tabulated data in their report while the maximum spring deflection (W_{1max}) was interpreted from data plotted in their report. They define normal deflection as "the average deflection observed during the months of August, September, and October prior to the first freeze." Both W_{1n} and W_{1max} are average values determined from 10 locations within each test section. The next column shows the percent increase in deflections (Δ) during the spring period.

The last column shows the time (t_{20}) from the onset of thawing to recovery of all but 20% of W_{1n}. This recovery time was arbitrarily selected to eliminate the long, slow recovery period leading into the fall season, which is of minor consequence in the performance of the pavement after thaw.

METHOD OF ANALYSIS

My analysis assumes that the increase in pavement deflection is wholly attributable to the weakening of the subgrade as a result of freezing and thawing. Obviously, changes in the stiffness of the pavement and the base and subbase material also probably occurred. However, neither of these factors could be quantified for this analysis, so they are not directly considered.

Data were also unavailable on several other potentially significant factors, including moisture content, dry density, proximity of the water table, and precipitation. Even so, it was felt that any sensitivity to the severity of the climate and the other factors available could be identified. To do this, empirical relationships between the dependent variables Δ and t_{20} and the independent variables W_{1n}, I, N, D, and F were assumed (Δ was also considered as an independent variable in evaluating t_{20}). The validity of these relationships was tested by multiple linear regression analysis and analysis of variance.

A visual inspection of the data revealed that the independent variables might be linearly related to the dependent variables. Therefore, the following expressions were tried.

$$\Delta = a_0 + a_1 W_{1n} + a_2 I + a_3 N + a_4 D + a_5 F \quad (1)$$

and

$$t_{20} = b_0 + b_1 W_{1n} + b_2 I + b_3 N + b_4 D + b_5 F + b_6 \Delta \quad (2)$$

where the subscripted terms a and b are the regression coefficients. Second degree governing equations were also analyzed to allow for nonlinear relationships, but the results were not significantly different. Only the results of the first degree equations are reported here.

The statistical analysis employed has been described by Robbins and Chamberlain (1973). It employs a multiple linear regression analysis of the functional relationships between the independent and dependent variables of interest while allowing the successive selection of the most influential independent variables with respect to the variance reduction of the dependent variable. The acceptance or rejection of a variable was governed by an F test in which the maximum probability level (α) for rejecting a variable could be selected as desired.

A 5% α level was used. The α value governing the entering or removal of an independent variable allowed the testing of the contribution of that variable to the reduction in variance of the dependent variable in the presence of any other variables previously accepted. Once a new variable was accepted, all other accepted variables were subjected to the F test and any that were rejected were removed and placed in the list to be reconsidered. The process of judging acceptance and rejection continued until no more variables passed the F test.

The statistical analysis also provided a measure of the strength of the linear relationship between variables through the correlation coefficient r. If the data points lay on a straight line, the correlation coefficient would be ± 1. If the data points were randomly scattered, the correlation coefficient would be 0. Another statistical element, the standard error, provided a measure of the scatter of the data about the regression line. For normally distributed data, approximately two-thirds of the data points fall within ± one standard error, while 95% fall within ± two standard errors.

RESULTS OF ANALYSIS

Change in resilient deflection due to thawing, Δ

The results of the regression analysis (Table 3) for Δ revealed that only the frost classification F was significant at a probability of occurrence level ($1-\alpha$) of 95% or better. The correlation coefficient was 0.50 and the standard error 39.55. Figure 2a illustrates the data of Scrivner et al.

Table 3. Results of regression analysis.

Dependent variable	Independent variables entered	Independent variables accepted $\alpha \leq 5\%$	Probability of falsely accepting a variable α (%)	Equation coefficients: Intercept a_0	Equation coefficients: Slope a_n	Correlation coefficient	Standard error
Δ%	W_{1n}, I, N, D, F	F	1	-42.69%	32.905%/unit	0.50	39.55
Δ	W_{1n}	not passing	31	39.00%	14.231%/milli-inch	0.22	44.52
Δ	I	not passing	52	56.25%	0.0078%/°F-day	0.13	45.20
Δ	N	not passing	>75	61.68%	1.063%/unit	0.05	45.56
Δ	D	not passing	>75	61.83%	0.0835%/inch	0.50	39.55
Δ	F	F	1	-42.69%	32.905%/unit	0.03	45.58
t_{20} days	W_{1n}, I, N, D, F, Δ	D	1	52.59 days	-0.144 day/inch	0.51	5.10
t_{20}	W_{1n}	W_{1n}	5	42.29 days	3.450 days/milli-inch	0.41	5.42
t_{20}	I	not passing	6	51.48 days	-0.00299 day/°F-day	0.40	5.45
t_{20}	N	not passing	7	45.95 days	1.091 days/unit	0.38	5.50
t_{20}	D	D	1	52.59 days	-0.144 day/inch	0.51	5.10
t_{20}	F	not passing	37	43.00 days	1.667 days/unit	0.19	5.83
t_{20}	Δ	not passing	30	46.56 days	0.0288 day/%	0.22	5.79

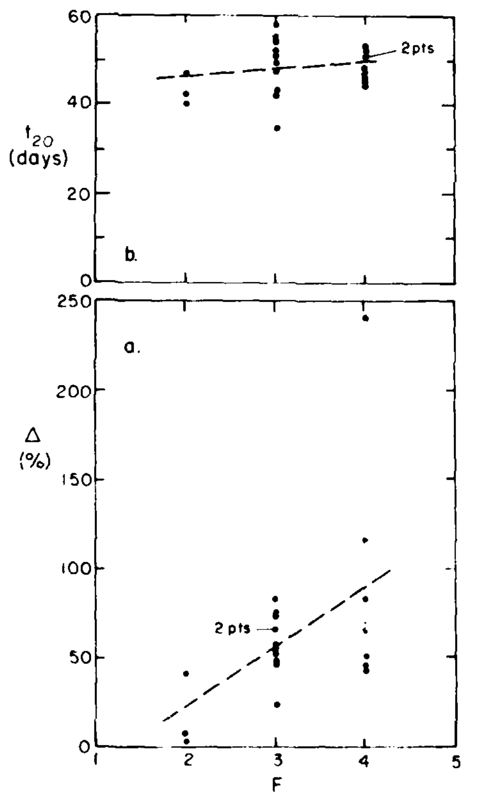


Figure 2. Data points and regression line for Δ and t_{20} versus F.

(1969) and the best fit line in the Δ versus I plane. There is a sharp increase in Δ with increasing frost susceptibility and considerable scatter in the data, reflected by the relatively low correlation coefficient and the high standard error.

No other variable passed the desired F test of $\alpha = 5\%$. In fact, none of the remaining independent variables passed an F test for $\alpha = 25\%$. In the presence of all other parameters, the most influential parameter on Δ is the frost classification; the inclusion of any of the other variables would not contribute significantly to the decreasing of the variance in Δ.

It was also desired to test the individual contributions of each independent variable on Δ. The functional relationships were assumed to be of the form:

$$\Delta = c_0 + c_1 X \tag{3}$$

where X is the independent variable of interest and c_0 and c_1 are the regression coefficients. The results of this analysis are given in Table 3. The frost susceptibility classification of the subgrade remained the most significant parameter. The depth of frost penetration was the least significant. The probability of any variable other than the frost classification significantly influencing the reduction in variance in Δ was no better than 30%, so all other variables were rejected by the

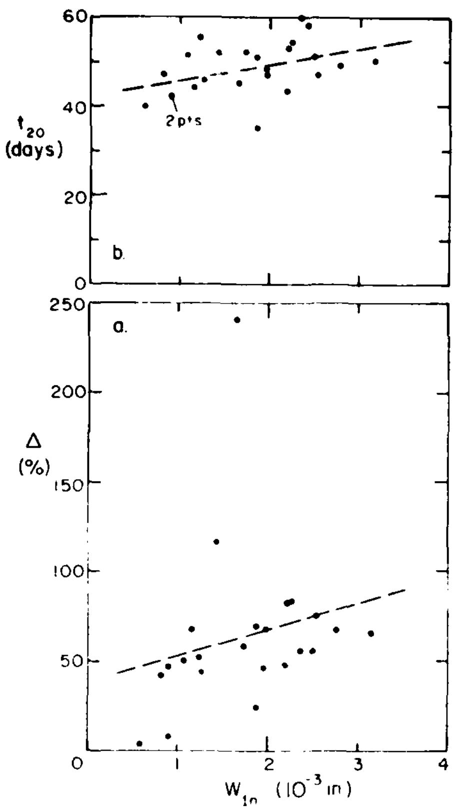


Figure 3. Data points and regression line for Δ and t_{20} versus W_{1n}.

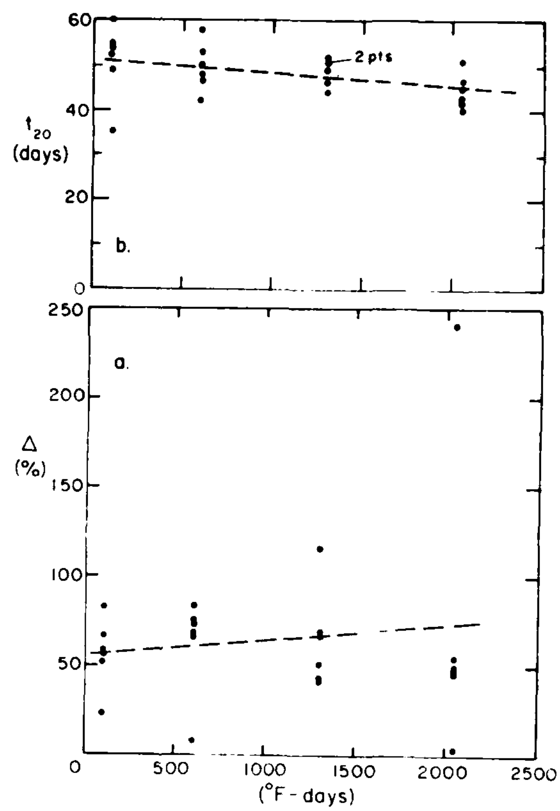


Figure 4. Data points and regression line for Δ and t_{20} versus I.

F test.

The linear fits established by the regression analysis are plotted along with the data of Scrivner et al. (1969) in Figures 2a-6a. The following trends can be observed:

1. Δ increases significantly with increasing F
2. Δ increases with increasing W_{1n}
3. Δ increases slightly with increasing I
4. Δ increases slightly with increasing N
5. Δ increases slightly with increasing D

However, since the probabilities of falsely accepting the variables W_{1n}, I, N, and D are so great, the use of their linear fits is questionable.

Recovery time after onset of thawing, t_{20}

The results of the statistical analysis for t_{20} (Table 3) show that the depth of frost penetration D is the most significant parameter in the presence of the others (α = 1%) and that no other variable passes the F test for α = 5%. When considered separately, the variables W_{1n}, I, and N pass F tests α = 5, 6, and 7%, respectively. The α levels for the remaining two parameters, Δ and the frost classification, were very high, so they are not considered statistically significant.

As illustrated in Figure 6b, the recovery time t_{20} decreases with increasing depth of frost penetration D. The fit of D to t_{20} appears to be a little better than that of F to Δ. The correlation coefficient is 0.51 and the standard error is 5.10. The results of the individual linear fits between t_{20} and the independent variables are given in Table 3 and illustrated in Figures 2b-6b and 7 along with the data of Scrivner et al. (1969). The following trends were observed:

1. t_{20} increases slightly with increasing F
2. t_{20} increases slightly with increasing W_{1n}
3. t_{20} decreases slightly with increasing I
4. t_{20} increases slightly with increasing N
5. t_{20} decreases with increasing D
6. t_{20} increases slightly with increasing Δ

DISCUSSION OF RESULTS

Change in resilient deflection due to thawing, Δ

Of special interest in this analysis is the observation that *the percent increase in pavement deflection upon thawing is not significantly related*

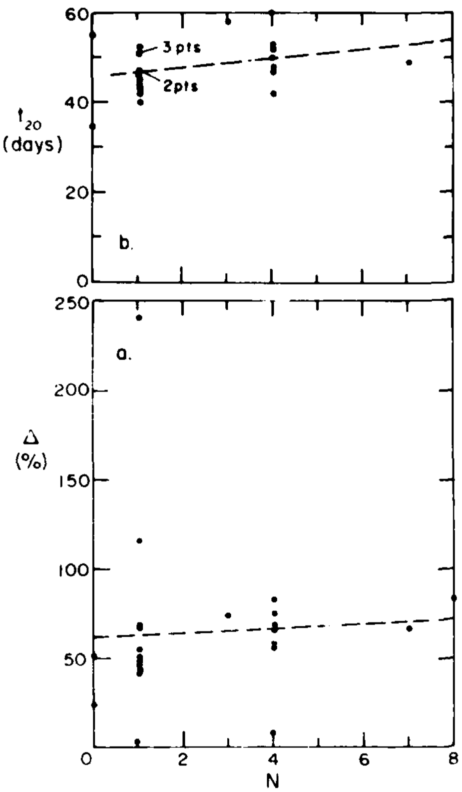


Figure 5. Data points and regression line for Δ and t_{20} versus N.

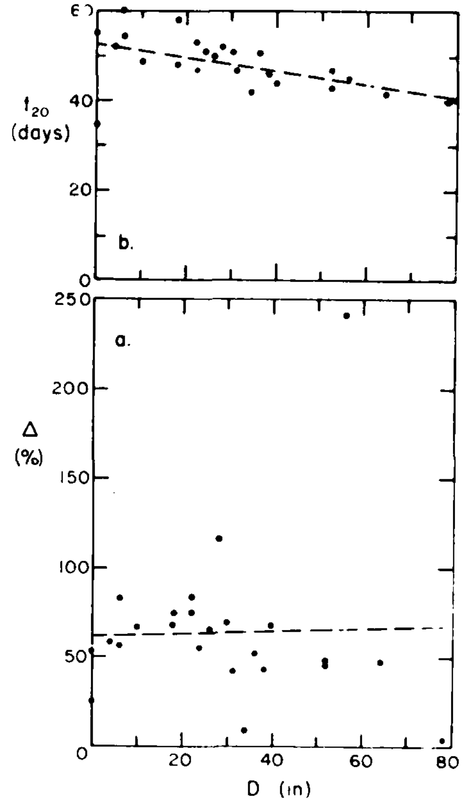


Figure 6. Data points and regression line for Δ and t_{20} versus D.

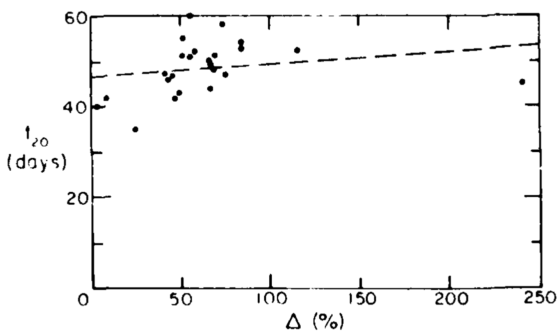


Figure 7. Data points and regression line for t_{20} versus Δ.

to the freezing index. Since a similar observation was made by the Canadian Good Roads Association (1965) from the results of Benkelman beam rebound tests in Canada, it can be assumed that this result of the analysis is reasonable. The significance of this observation is that if frost penetrates into the subgrade of F2, F3, or F4 frost classification, Table 2, the potential loss in pavement carrying capacity is the same regardless of the severity of the freezing index.

The ranking by α-level for W_{1n}, I, N and D revealed that α = 1, 31, 52, and >75%, respectively. Because the probabilities of rejecting all variables but F, even when variables were considered separately, were 30% or better, only F can be considered as a predictor of Δ. The reliability of using F as a predictor for Δ is poor as revealed by the large standard error. The scatter may be a result of the interpretation required to extract the data from the report of Scrivner et al. (1969) or, more likely, the result of the unavailability of all significant variables for the analysis.

That the most significant variable influencing the reduction in variance in Δ was the frost classification confirms the need to carefully select the soil materials for pavement structures and to provide a means of accurately identifying the frost weakening characteristics of soils. Because the weakening of asphaltic pavement structures during thawing is a system response involving both surfacing, and compacted and natural soil materials, any reliable frost-weakening criteria must be developed in terms of the in-place conditions of each layer.

The most direct approach to this analysis would require in-place measurement of pavement deflections under repeated loading along with measurement of the above-mentioned properties, and laboratory repeated-load tests on each of the components of the pavement system. A layered system mathematical analysis would be required to relate the laboratory observations to the field performance. These methods are presently being used at CRREL (Johnson et al. 1978). If a sufficient number of laboratory and field observations were correlated, the laboratory and field test could probably be replaced or supplemented by common soil index tests such as grain size, Atterberg limits, dry density, moisture content, permeability, and soil suction.

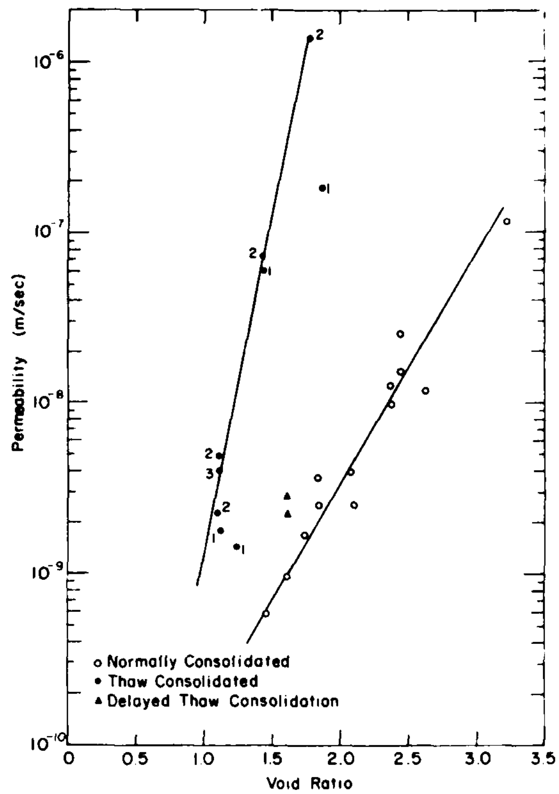


Figure 8. Permeability vs void ratio for Toledo Penn 7 dredged material. Numbers adjacent to points indicate the number of freeze-thaw cycles. (From Chamberlain and Gow 1978)

Recovery time after thawing, t_{20}

An unanticipated result of this analysis is that *the recovery time decreases with depth of freezing and the freezing index;* that is, the greater the freezing index, the greater will be the depth of freezing and the shorter the recovery time. This observation originally conflicted with the author's intuitive judgment that the recovery time would be longer with increasing frost depth because the greater frost depth would require a longer thaw period and would cause a change in deformational properties over a greater depth. A closer look at the frost penetration-time curves (Fig. 1) and recovery time data in Table 2 reveals that the thaw period (a few days to two weeks) is relatively short in comparison with the recovery period (35 to 60 days) and, thus, is not the dominant factor in determining the length of the recovery period.

A possible explanation for the shorter recovery period occurring for the case of deepest frost penetration is that the freezing and thawing process changes the particle arrangement in the subgrade soil and gives it a higher permeability, thus improving the drainage. Recent tests by the author (Chamberlain and Blouin 1978, Chamberlain and Gow 1978) revealed that the permeability of a soil can be increased by as much as two orders of magnitude by frost action. Figure 8, for example, shows the large increase in permeability for a dredged material. It appears that the shorter recovery time for the greater depth of freezing may be a consequence of the improved drainage conditions imparted by frost action.

The frost penetration depth D was by far the most significant variable affecting t_{20} in the presence of all others. The probability of falsely accepting this variable is 1%. In the presence of D no other variable would pass a significance level of even $\alpha = 20\%$, so all other variables were rejected. However, when considered singly, the W_{1n}, I, and N variables passed the 5%, 6%, and 7% significance levels respectively. This means that W_{1n}, I, and N correlate strongly with D and are good predictors of t_{20}, that given the choice of these four variables D would be the best predictor of t_{20}, and that including W_{1n}, I, and/or

N would not contribute significantly to the prediction of t_{20} in the presence of D; i.e., the accuracy of the equation

$$t_{20} = a_0 + a_1 D \quad (4)$$

in predicting t_{20} is not improved significantly by including the variables W_{1n}, I, or N.

Even when considered singly in the statistical analysis, the variables F and Δ fail to pass a significant level of 25%, and thus cannot be considered as reliable predictors or indicators of t_{20}.

The reliability of D as a predictor of t_{20} is good as revealed by the relatively small standard error on the regression line between D and t_{20}. However, because of the limited number of sites evaluated, the results should not be interpreted as establishing a universal relationship between D and t_{20}. The analysis should be tested on a great many more sites.

CONCLUSIONS

The most interesting observations of this statistical analysis are that *the freezing index is not a significant parameter in determining the percent increase in pavement deflection during thawing* and that *the recovery time decreases with the depth of freezing*.

The necessity for careful selection of soil materials for pavement systems is reflected in the observation that the most significant variable affecting the reduction in variance in Δ was the frost susceptibility classification.

Since the standard error was large for the linear fit between Δ and F, the established relationship may not give an accurate estimate of Δ from knowledge of F. Much more study is required to analyze this relationship and other variables such as moisture content, dry density, and depth to water table must be included.

Although the recovery time was found to be strongly related to the depth of freezing, the number of sites evaluated was not large. A great many more sites must be evaluated to provide a full test of the results.

LITERATURE CITED

Canadian Good Roads Association (1965) A guide to the structural design of flexible and rigid pavements in Canada. Roads and Transportation Association of Canada, 65 p.

Chamberlain, E.J. and S.E. Blouin (1978) Densification by freezing and thawing of fine material dredged from waterways. *Proceedings of the 3rd International Conference on Permafrost*. Edmonton, Alberta: National Research Council, Canada, p. 622-628.

Chamberlain, E.J. and A.J. Gow (1978) Effect of freezing and thawing on the permeability and structure of soil. *Proceedings of the 1st International Symposium on Ground Freezing*. Ruhr-University, Bochum, W. Germany, p. 31-44.

Johnson, T.C., D.M. Cole, and E.J. Chamberlain (1978) Influence of freezing and thawing on the resilient properties of a silt soil beneath an asphalt concrete pavement. U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report 78-23, 49 p. ADA061328.

Robbins, R. and E. Chamberlain (1973) Stepwise multiple regression analysis in the Basic language. CRREL Technical Note (unpublished).

Scrivner, F.H., R. Peohl, W.M. Moore and M.B. Phillips (1969) Detecting seasonal changes in load-carrying capabilities of flexible pavements. National Cooperative Highway Research Program, Report No. 76, 37 p.

U.S. Army (1965) Pavement design for frost conditions. U.S. Army Technical Manual, TM 5-818-2, 66 p.

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Chamberlain, Edwin J.
A statistical evaluation of soil and climatic parameters affecting the change in pavement deflection during thawing of subgrades / by Edwin J. Chamberlain. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1980.
v, 10 p., illus.; 28 cm. (CRREL Report 81-15.)
Prepared for Directorate of Military Programs - Office of the Chief of Engineers by Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory, under DA Project 4A762730AT42.
Bibliography: p. 10.
1. Deflection. 2. Freeze-thaw. 3. Pavement bases. 4. Pavements. 5. Soils. 6. Statistical analysis. I. United States. Army. Corps of Engineers. II. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. III. Series: CRREL Report 81-15.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 701-748/127

DATE
FILMED

-8